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Multi Source Bidirectional DC/DC Converter by Using PV-Wind-Battery based Integration for Domestic Applications

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Abstract

Renewable energy sources are becoming more attractive due to their eco-friendly nature. As conventional energy sources are polluting environment, it has become imperative to shift to renewable energies. PV and wind are popular renewable sources because of their abundance availability and cost effectiveness. But, renewable do not being able to supply continuous power owe to intermittency of renewable sources. This issue can be addressed by efficiently integrating battery with renewable sources. The usual approach for this is to use dedicated single-input converters one for each source. In this, the sources are connected to a common dc bus. The special converters which are used for the integration purpose would not work properly due to renewable intermittency. The efficiency of integrated system would be decreased due to multiple power conversion stages. So, the major challenge is to decrease power conversion stages and hence losses of hybrid system. A control technique has been proposed in this work for tracking Maximum Power Point (MPP) of both wind turbine and photovoltaic array through adjusting the duty cycle ratios of switches used in converters under varying climatic conditions.

Keywords: Duty Cycle, Maximum Power Point, Power Conversion, Solar Photovoltaic (PV), Wind Energy

1. Introduction

Ever rising energy demand and global warming due to depletion of fossil fuels is the main motivation behind shifting to renewable sources of power generation. In those renewable sources, solar and wind are most popular ones due to their eco-friendly nature and economical power harnessing[1–3]. However the intermittency nature of the solar and wind availability makes adequate storage, an integral part of the system. This battery integration leads to hybrid PV-wind energy systems. In addition, there would be reduction of overall system efficiency due to multiple power conversion stages[4].

A doubly excited permanent magnet brushless machine is used for the wind generator, in which maximum power & high efficiency is extracted by regulating TSR. The coupled transformer is used to get high output voltage and stable power from integration of two low voltage input sources. But all this arrangement eventually increases the system complexities[5]. In this current work, a hybrid wind-PV power generation system is proposed, with an inverter and buck–boost multi source converter. It simplifies the configuration and reduces the cost. The main objective of configuration is to improve voltage regulation of dc-link[6]; which is addressed well in this arrangement.

The PV solar cell extracts energy from sun and converts it to electricity. The main challenges in PV systems are[7]:

- PV cells are costly.
- Conversion efficiency of electric power by PV cells is low.
- At low radiations the efficiency of conversion is 9- 16%[8].

This is due to fact that PV generations depend on weather conditions[9–12]. The solar cell has typical non-

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linear v-i characteristics. It changes with variation in insolation, temperature and load impedance. Insolation and temperature are dynamic in nature. The point at which PV array provides maximum power is unpredictable. We can get MPP by search algorithms and calculations[13,14]. These optimum operating points of renewable sources are obtained using MPPT techniques. A symbolic representation of a PV panel is shown in Figure 1.

Generally, commercially used PV modules have efficiency between 6 to 16%. This variation in efficiency depends on the technology used. To get high conversion efficiency, there are primarily two techniques used[15].

- The first technique depends on tuning both mechanical and electrical equipment. Here sun trackers are used to track best position to extract maximum energy from sun.
- The second technique wholly depends on electrical equipment. They are helpful in tuning electrical parameters at PV module output. It makes PV module to operate at optimal operating point.

A lot of work has been done on integration of PV & wind sources and their sizing and optimization[16,17] addresses the control techniques and modelling aspects

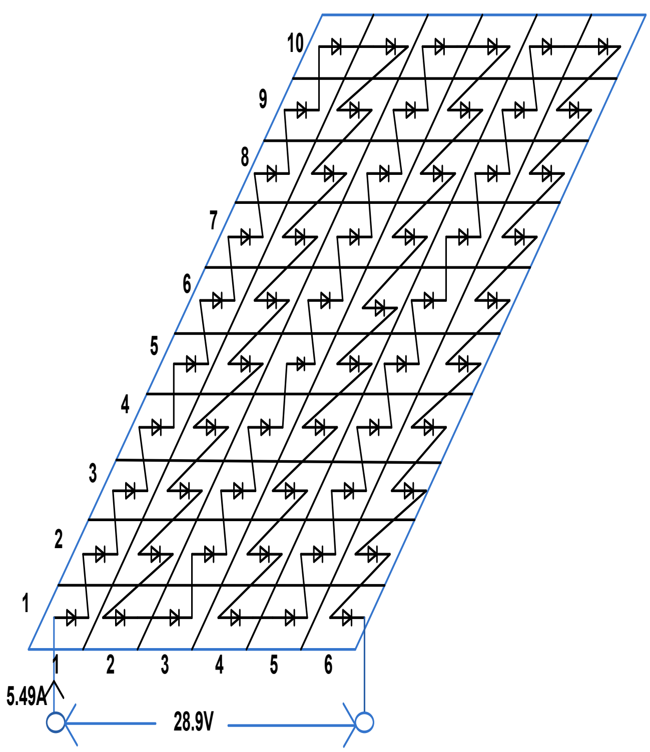

Figure 1. A photo-voltaic cell stack.

of stand-alone systems. In non-isolated topologies, all the power ports share a common ground. A parallel or series combination is used at input side to get multi-port dc/dc converters. Here, both the storage and sources are connected to dc-link through their dedicated converters.

It requires an efficient strategy to improve the regulation of dc bus voltage in case of grid connected PV-wind power generation system. Such a system can improve power quality by reducing dc-link voltage and optimising size of dc-link capacitor. PV and wind systems are integrated along with battery where power sources are interface with dc bus through their dedicated converters[18].

In order to match dc bus voltage, boost converter is fed from PV and wind generation in the six-arm topology converter. A multiport converter is made out through the magnetic coupling approach where each terminal is combined by using multi-winding transformer[19–21]. In order to attain soft switching by varying phase shift, leakage inductance of transformer and snubber capacitors are used.

However, in spite of simple topology, the employed control scheme needs thorough investigation to address the complexities. Hybrid PV–wind electricity generation for grid connected applications has been an important area of research[22]. Main objectives of the present work are:

- To give better control proposal for optimum charging of battery from different sources.
- Delivering uninterruptible power to the loads.
- Supplying extra power from renewable sources to grid and charging battery from grid whenever possible.

The proposed converter configuration reduces losses by reducing number of conversion stages and components used. In this configuration, reliability and efficiency of system are increased. The multi-source transformer coupled bidirectional converter is the heart of this system configuration. It acts as an interface between storage elements and power sources[23].

The proposed configuration has the following advantages:

- There is galvanic isolation between power sources and load. This provides safety for the system[24].
- The proposed scheme can control battery charging, bidirectional power flow, MPPTs of PV and wind through controlling the switching.
- Utilization factor of converter is improved due to elimination of dedicated converters for each source.

- Voltage boosts due to series connection of PV and battery. It is further boosted by dual active bridge step-up transformer.

There is vast growth in solar and wind energy due to improvements in technologies which has reduced the cost of PV and wind generation equipment. Even government is supporting both industrial and public participation in utilization and development of renewable sources by making many favourable policies[25,26].

In this paper, the PV-wind-battery based integration system has been developed for the domestic applications. The paper organization spreads in four sections. Section 1 gives introduction to the work, Section 2 describes about modelling of two diode equivalent circuit of PV cell and Section 3 demonstrates about whole system analysis and lastly discuss about simulation results and conclusion.

2. Modeling of Two Diode Photovoltaic System

Solar cells are constructed with two p-n junctions made-up on an emaciated wafer of semiconductor. When junctions are out to light, semiconductor absorbs photons with energy g0reater than band gap energy and generates electron-hole pairs. These electron-hole pairs cross the band gap of p-n junctions and generate electric power. The PV cell is designed like current source associated with two parallel diodes to get good performance rather than conventional equivalent PV circuit. The two diodes illustrate nonlinear stochastic nature of i-v characteristics of PV[19]. Figure 2 depicts equivalent circuit of two diode model PV with linear and nonlinear elements.

The equivalent circuit of PV consist of ideal current source (I), two diodes (d_1, d_2), shunt resistance (R_{SH}) and series resistance (R_{SE}). The cascaded relation of ideal current and voltage source is providing best characteristics of two diode model of PV[20]. Furthermore, various series and parallel connection of PV cells are extended to enhance current and voltage ratings of system. For steady state mathematical study of PV, Kirchhoff's voltage and current laws are useful to two diode model PV cell.

The output current (I_{PV}) is equal to subtraction of diode (d_1) and diode (d_2) currents (I_{d1}, I_{d2}), shunt resistance current (I_{SH}) from current produced by photon (I) is mentioned in Equation 1.

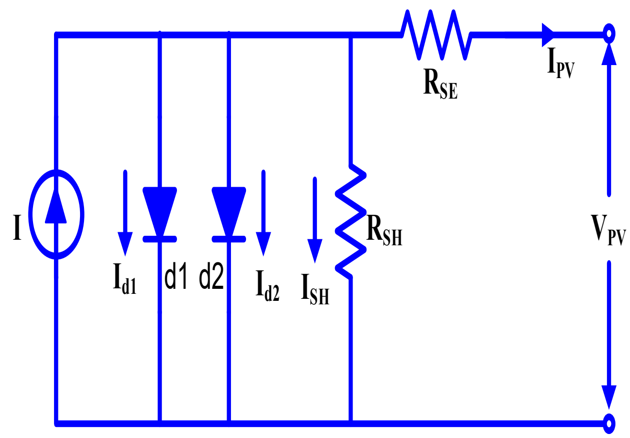

Figure 2. Equivalent circuit of the two diode model of PV cell.

$$I_{PV} = I - I_{d1} - I_{d2} - I_{SH} \tag{1}$$

The parameters of diode current consist of voltage across diodes ($V_{PV}+I_{PV}.R_{SE}$) and charge produced by PV (q), safety factor of diodes (η_1, η_2), temperature of device (T) and Boltzmann's constant(K).

The thermal voltage of two diodes (V_{t1}, V_{t2}) is equal to multiplication of Boltzmann's constant (K) and temperature of diode (T) to charge produced by diode (q), expressed in Equation 2. and Equation 3.

$$I_{PV} = I - I_{Od}\left(e^{\frac{V_{PV}+I_{PV}R_{SE}}{\eta_1 V_{t1}}} - 1\right) - I_{Od}\left(e^{\frac{V_{PV}+I_{PV}R_{SE}}{\eta_2 V_{t2}}} - 1\right) - I_{SH} \tag{2}$$

$$I_{PV} = I - I_o\left(e^{\frac{q\times V_d}{\eta\times KT}} - 1\right) - I_{SH} \tag{3}$$

The PV current (I) presented in terms of short circuit current (I_{SCR}), reference of Insolation (G_{CR}), Instantaneous Insolation (G_C), temperature coefficient of PV (αT), reference temperature (T_{CR}) and instantaneous temperature (T_C) expressed in Equation 4.

$$I = I_{SCR}\frac{G_C}{G_{CR}}\left[1+\alpha_T(T_C - T_{CR})\right] \tag{4}$$

$$I_{od} = I_{OR}\left(\frac{T_C^{\ 3}}{T_{CR}^{\ 3}}\right)e^{\left[\frac{1}{T_{CR}}-\frac{1}{T_C}\right]\frac{qe_g}{\eta k}} \tag{5}$$

Equation 5 can express the initial dark (I) current produced in two diode model PV. This is directly proportional to ratio of instantaneous to reference temperature and dark current (I_{od}) at a reference temperature.

$$I_{SH} = \frac{V_{PV} + I_{PV} R_{SE}}{R_{SH}} \tag{6}$$

The shunt current of PV consists of voltage across load (V_{PV}), voltage across series resistance of PV (I_{PV} R_{SE}) and current in the shunt resistance expressed in Equation 6.

3. Whole System Analysis

The converter configuration is shown in Figure 4. It consists of dual active half bridge bidirectional converter with single-phase full bridge inverter and bidirectional buck boost converter. Advantages of this configuration are:

- Power conversion stages are reduced.
- High efficiency compared with existing models.
- Simple topology.

By controlling voltage of one dc link at one side of transformer we can control other dc link voltage at other side. The advantage of this configuration is that any converters can be integrated additionally with either of primary and secondary dc-links of transformer. An inverter is integrated at secondary side of transformer whereas bidirectional buck boost converter is integrated at primary side. The modes of operation of whole conversion system have been shown in Figure 3. PV system in series with battery is set as input to half bridge of primary side of transformer. Bidirectional converter is used to

- Collect power from PV along with controlling charging and discharging of battery.
- MPP tracking.
- Voltage boosting.

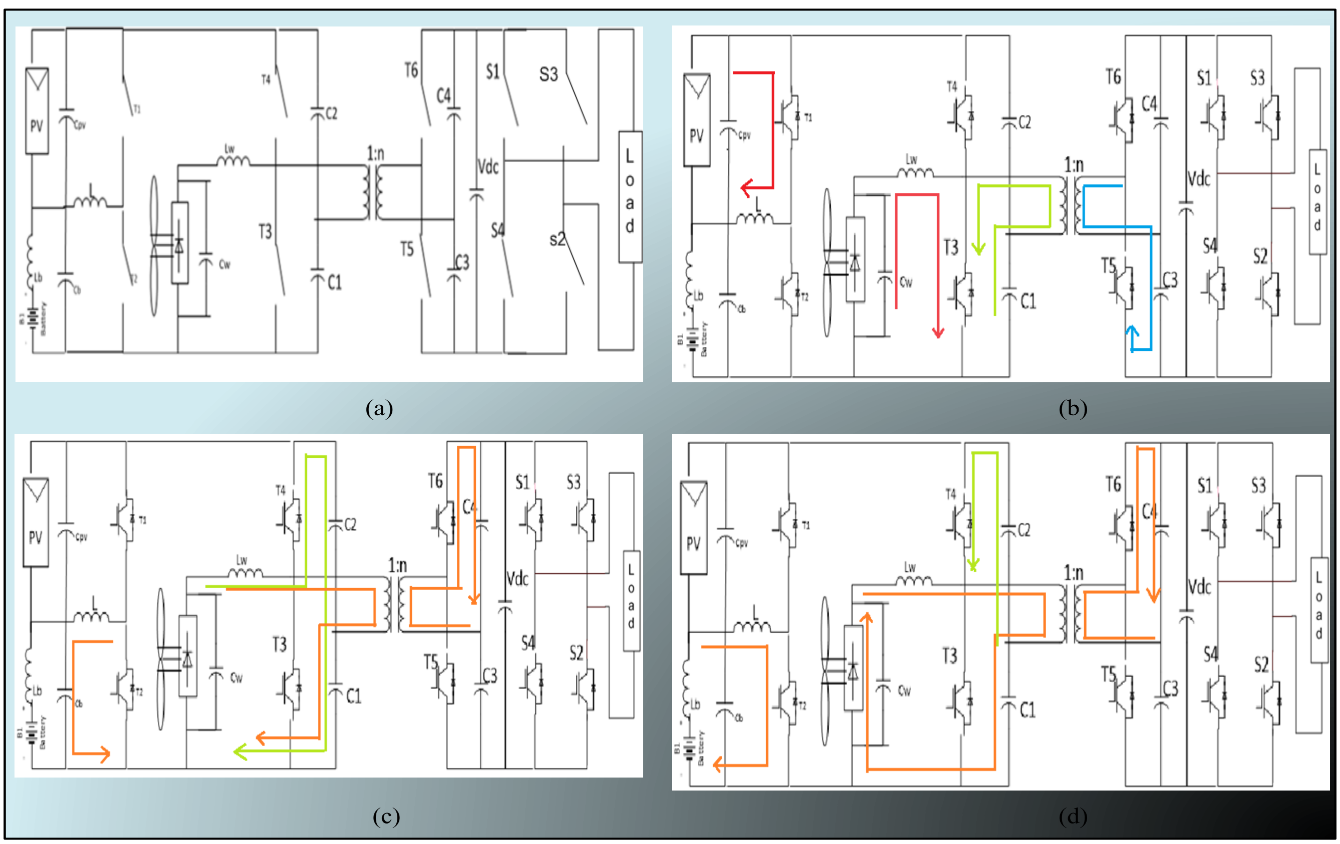

Figure 3. Various operating modes of the multi-input transformer-coupled bidirectional dc–dc converter. **(a)** Proposed converter configuration. **(b)** Operation when switch T3 is turned ON. **(c)** Operation when switch T4 is ON, charging the capacitor bank. **(d)** Operation when switch is T 4 ON, capacitor C2 discharging.

The dual active half bridge is the dedicated converter for interfacing wind source to dc bus, while a unidirectional half bridge converter is needed to control power from wind source. An inductor is used to get smooth variation in current so as to track MPP of wind energy. The complete system is represented in block form in Figure 5.

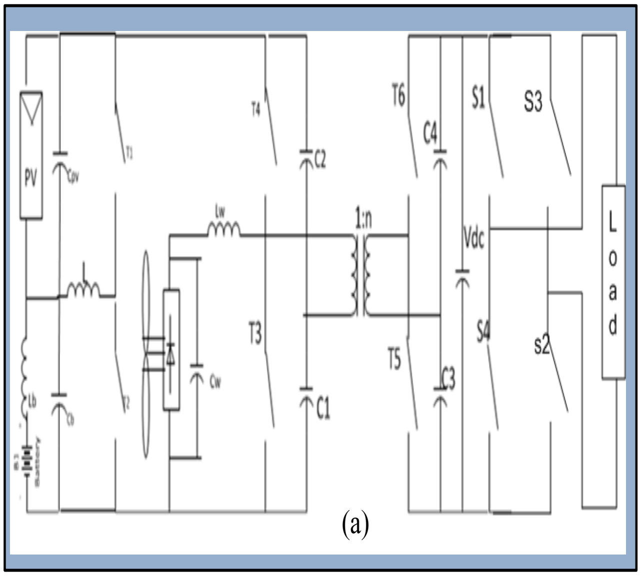

Figure 4. Converter configuration of whole system.

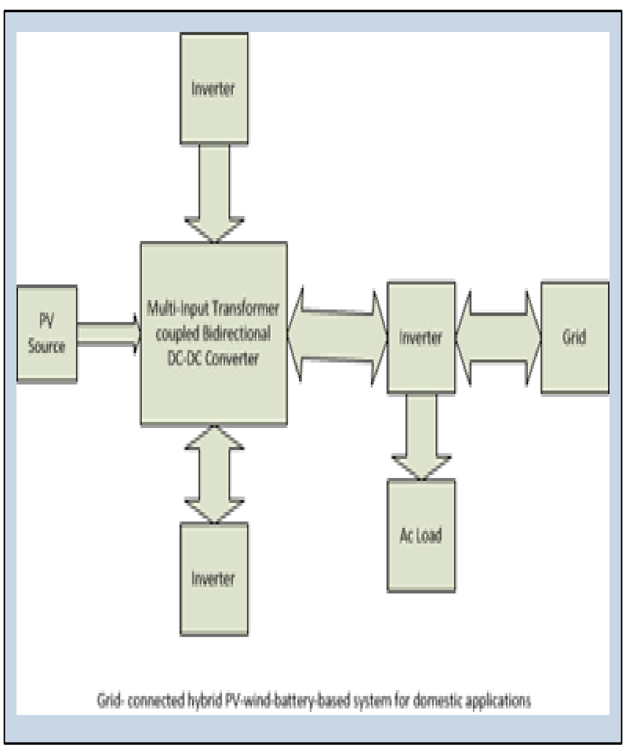

Figure 5. Block diagram of whole system.

When T_3 is on,
Primary side voltage of transformer is

$$V_P = -V_{C1} \tag{7}$$

Voltage of secondary side of T/F is

$$V_S = nV_P = -nV_{C1} = -V_{C3} \tag{8}$$

Therefore

$$V_{C3} = nV_{C1} \tag{9}$$

Inductor voltage at half bridge converter is

$$V_{LW} = V_W \tag{10}$$

When T_4 is on, (i.e T_3 is off)

$$V_P = V_{C2} \tag{11}$$

$$V_S = nV_P = nV_{C2} = nV_{C4} \tag{12}$$

Inductor voltage

$$V_{LW} = V_W - (V_{C1} + V_{C2}) \tag{13}$$

From above conditions it can be proved that

$$V_{C1} + V_{C2} = \frac{V_W}{1 - D_W} \tag{14}$$

Dc link voltage

$$V_{DC} = V_{C3} + V_{C4} = \frac{nV_W}{1 - D_W} \tag{15}$$

Therefore, from this equation, the voltage of secondary side dc-link is a function of duty cycle, ratio of primary side converter and turns ratio of transformer.

$$V_b = \frac{D}{1 - D} V_{PV} \tag{16}$$

The output voltage of dual active half-bridge converter is given by

$$V_{DC} = n(V_{C1} + V_{C2}) = n(V_b + V_{PV}) = \frac{nV_W}{1 - D_W} \tag{17}$$

The PV, battery current and average inductor current over a time period are related as

$$I_L = I_{PV} + I_b \tag{18}$$

Hence by controlling I_L, battery current I_b and PV current Ipv can be controlled. From this, it is evident that MPP operation can be controlled by controlling inductor current I_L while maintaining suitable battery charge stage.

In stand-alone mode, energy generated from PV and wind sources at their maximum power point feeds the power to load according to load demand.

In this stand-alone case, power balance can be ensured by deviating MPP of one or both sources according to load demand. However, in grid-connected systems both sources always operate at their MPP. The power is drawn from grid to charge battery in absence of both renewable sources.

The power balance equation of system is as follows

$$V_W I_W + V_{PV} I_{PV} = V_g I_g + V_b I_b \tag{19}$$

The peak value of voltage of an inverter is

$$\hat{V} = m_a V_{DC} \tag{20}$$

The dc-link voltage is

$$V_{DC} = n(V_{PV} + V_b) \tag{21}$$

Hence from Equations (19) and (20),

$$V_g = \frac{1}{\sqrt{2}} m_a n(V_{PV} + V_b) \tag{22}$$

In half-bridge converter

$$V_W = (1 - D_W)(V_{PV} + V_b) \tag{23}$$

Now, substituting V_w and V_g in Equation (19)

$$V_{PV} I_{PV} + (V_{PV} + V_b)(1 - D_W)V_W = V_b I_b + \ldots\ldots \frac{1}{\sqrt{2}} m_a n(V_{PV} + V_b)V_W \tag{24}$$

After generalization

$$I_b = I_{PV} \frac{1 - D_{PV}}{D_{PV}} + I_W \frac{1 - D_W}{D_W} - I_{PV} \frac{m_a n}{D_{PV}} \tag{25}$$

From Equation (25), it can be deduced that if there is any change in extraction of power from renewable sources, we can control battery current by controlling grid current I_g. Hence, according to availability of grid, PV, wind energy and charge status of battery, bidirectional converter is controlled. Higher priority is given to battery charging in order to guarantee uninterrupted power supply to loads. The extra power from renewable sources which is left after battery charging current limit $I_{b\ max}$ is reached is then fed to grid. Battery is charged from grid in absence of these sources.

4. Simulation Results

The whole system simulation has been performed in MATLAB/ SIMULINK to validate theoretical analysis of integrated system.

4.1 Matlab Model of Converter Configuration

A MATLAB model is shown in Figure 6 in which PV and battery are connected in series and isolation transformer

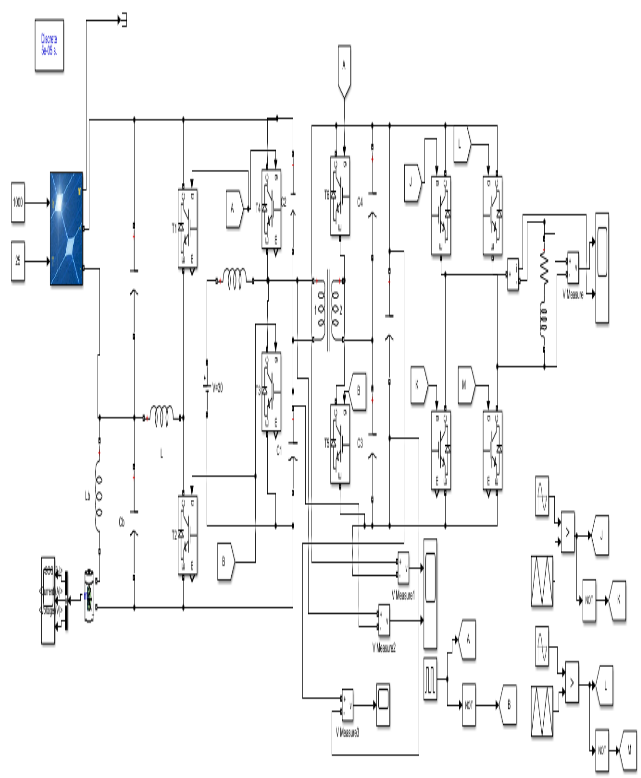

Figure 6. MATLAB model of PV and dc voltage integration.

is used for boosting purpose. A bidirectional converter is used to control power from PV array. Both of the sources are connected to dc bus at primary side of dual active bridge high frequency transformer. A Unipolar pulse width modulation technique is utilized at inverter side and related voltage and current waveforms are depicted in Figure 7. The voltage waveform across dc-link on secondary side of transformer is also depicted in Figure 7.

4.2 MATLAB Model of PV with MPPT and Wind Sources Integration

The MATLAB model of PV with MPPT and integration with wind is shown in Figure 8. A simple MPPT technique, Perturb and Observe method, is used at PV module to track and extract maximum power from PV and corresponding voltage and current waveforms at inverter output is shown in Figure 9. There is a slight distortion at first due to the tracking of MPP while settling to its steady state. The system parameters are presented in Table 1.

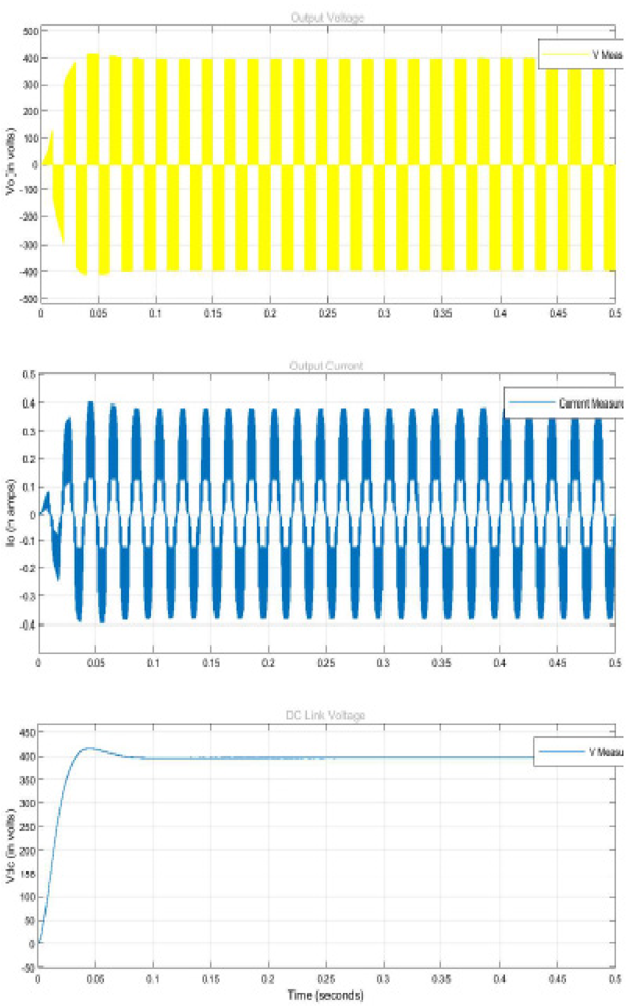

Figure 7. Output voltage, Output current and DC link voltage waveforms.

Table 1. Parameters of whole system

Solar PV power	525W I_{mpp} = 14.8 A V_{mpp} = 35.4 V
Wind Power	300W I_{mpp} = 8 A V_{mpp} = 37.5 V
Switching frequency	15KHz
Transformer turns ratio	6
Half-bridge boost converter Inductor, L_w	500uH
Bidirectional converter inductor L	3000uH
Primary and secondary capacitors C_1, C_2, C_3, C_4.	500uF
Secondary side DC link capacitor	2000uF
Battery Capacity & Voltage	400Ah , 36V

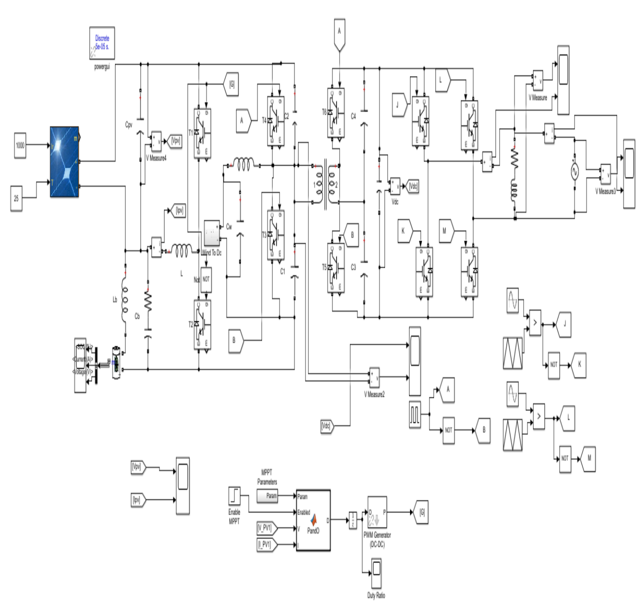

Figure 8. MATLAB model of PV with MPPT and Wind sources integration.

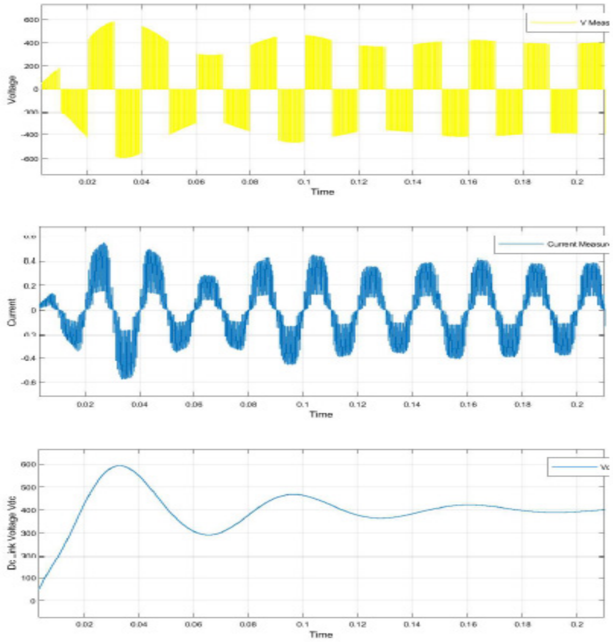

Figure 9. Output voltages, output current and DC link voltage waveforms of PV with MPPT and wind integration.

5. Conclusion

The whole system would provide maximum energy which is extracted from renewable and will keep portion of energy to battery which will again be reused whenever intermittency arises. By using this system, intermittency problem can be reasonably addressed at the expense of little complex control techniques. It is realized by the proposed bidirectional dc/dc converter followed by a conventional inverter. This system can perform in both grid connected and standalone modes. The proposed configuration can supply uninterruptible power to ac loads. In case of any surplus power from PV and wind, it is fed to grid.

In future, a versatile control strategy can be used to improve utilization factor of PV, wind and optimise battery capacities. In addition to that, quality of power and power flow management can be improved in case of grid-connected hybrid PV–wind-battery based systems feeding ac loads. Best MPPT techniques can be used for both wind and solar PV according to power handling capacities.

6. References

1. Giraud F, Salameh ZM. Steady-state performance of a grid-connected rooftop hybrid wind-photovoltaic power system with battery storage. IEEE Trans Energy Converters. 2008; 10(3):398-405.
2. Valenciaga F, Puleston PF. Supervisor control for a stand-alone hybrid generation system using wind and photovoltaic energy. IEEE Trans Energy Converters. 2005; 20(2):398-405. https://doi.org/10.1109/TEC.2005.845524
3. Liu C, Chau KT, Zhang X. An efficient wind-photovoltaic hybrid generation system using doubly excited permanent-magnet brush-less machine. IEEE Trans Ind Electron. 2010; 57(3):831-9. https://doi.org/10.1109/TIE.2009.2022511
4. Prakash S, Reddy BM. Techno-economic issues of grid connected large photovoltaic plants (A case study of 5 MW photovoltaic power plant at Prayagraj). Journal of Engineering Technology. ASEE publishers. 2019; 8(1):492-505.
5. Wai RJ, Lin CY, Chang YR. High step-up bidirectional isolated converter with two input power sources. IEEE Trans Ind Electron. 2009; 56(7):2629-43. https://doi.org/10.1109/TIE.2009.2018427
6. Chen YM, Liu YC, Hung SC, Cheng CS. Multi-input inverter for grid-connected hybrid PV/wind power system. IEEE Trans Power Electron. 2007; 22(3):1070 https://doi.org/10.1109/TPEL.2007.897117
7. Wai RJ, Lin CY, Chang YR. High step-up bidirectional isolated converter with two input power sources. IEEE Trans Ind Electron. 2009; 56(7):2629-43. https://doi.org/10.1109/TIE.2009.2018427
8. Xu L, Ruan X, Mao C, Zhang B, Luo Y. An improved optimal sizing method for wind-solar-battery hybrid power system. IEEE Trans Sustain Energy. 2013; 4(3):774-85. https://doi.org/10.1109/TSTE.2012.2228509
9. Chen YM, Cheng CS, Wu HC. Grid-connected hybrid PV/wind power generation system with improved DC bus voltage regulation strategy. Proc 21st Annu IEEE Appl Power Electron Conf Expo (APEC); Texas, USA; 2006. p. 1088-94.
10. Kim SK, Jeon JH, Cho CH, Ahn JB, Kwon SH. Dynamic modelling and control of a grid-connected hybrid generation system with versatile power transfer. IEEE Trans Ind Electron. 2008; 55(4):1677-88. https://doi.org/10.1109/TIE.2007.907662
11. Karthik DR, Reddy BM, Kushwaha SKS. A PSCAD simulation on integration of multi-level converters with DC-DC converter for AC drive applications. 2016 International Conference on Circuit, Power and Computing Technologies (ICCPCT); Nagercoil, India; 2016. p. 1-6. https://doi.org/10.1109/ICCPCT.2016.7530191

12. Daniel SA, Ammasaigounden N. A novel hybrid isolated generating system based on PV fed inverter-assisted wind-driven induction generators. IEEE Trans Energy Convers. 2004 19(2):416-22. https://doi.org/10.1109/TEC.2004.827031
13. Reddy BM. Parametric analysis of the bidirectional soft switching DC/DC converter for the proton exchange membrane fuel cell hybrid electric vehicle. Power Research, CPRI Publishers. 2018 14(1). https://doi.org/10.33686/pwj.v14i1.142185
14. Qian Z, Abdel-Rahman O, Batarseh I. An integrated four-port DC/DC converter for renewable energy applications. IEEE Trans Power Electron. 2010; 25(7):1877-87. https://doi.org/10.1109/TPEL.2010.2043119
15. Karthik DR, Reddy BM, Reddy PK. A ZVS PWM three-phase current fed push-pull DC-DC converter in Microgrids. IJSETR. 2015; 4(8):2783-92.
16. Nejabatkhah F, Danyali S, Hosseini SH, Sabahi M, Niapour SM. Modelling and control of a new three-input DC-DC boost converter for hybrid PV/FC/battery power system. IEEE Trans Power Electron. 2014; 27(5):2309-24. https://doi.org/10.1109/TPEL.2011.2172465
17. Chiang HC, Ma TT, Cheng YH, Chang JM, Chang WN. Design and implementation of a hybrid regenerative power system combining grid-tie and uninterruptible power supply functions. IET Renew Power generation. 2010; 4(1):85-99. https://doi.org/10.1049/iet-rpg.2009.0033
18. Liu D, Li H. A ZVS bi-directional DC-DC converter for multiple energy storage elements. IEEE Trans Power Electron. 2006; 21(5):1513-7. https://doi.org/10.1109/TPEL.2006.882450
19. Chen YM, Liu YC, Wu FY. Multi-input DC/DC converter based on the multi-winding transformer for renewable energy applications. IEEE Trans Ind Appl. 2002; 38(4):1096-104. https://doi.org/10.1109/TIA.2002.800776
20. Zhao C, Round SD, Kolar JW. An isolated three-port bidirectional DC-DC converter with decoupled power flow management. IEEE Trans Power Electron. 2008; 25(5):2443-53. https://doi.org/10.1109/TPEL.2008.2002056
21. Ouyang Z, Zhang Z, Andersen MAE, Thomsen OC. Four quadrants integrated transformers for dual-input isolated DC-DC converters. IEEE Trans Power Electron. 2012; 27(6):2697-702. https://doi.org/10.1109/TPEL.2012.2186591
22. Al-Atrash H, Tian F, Batarseh I. Tri-modal half-bridge converter topology for three-port interface. IEEE Trans Power Electron. 2007; 22(1):341-5. https://doi.org/10.1109/TPEL.2006.889583
23. Reddy BM, Narendra CH, Rambabu CH. A ZVS PWM three-phase current fed push-pull DC-DC converter with fuel cell input. IJSETR. 2014; 3(12):3449-54.
24. Qian Z, Abdel-Rahman O, Al-Atrash H, Batarseh I. Modelling and control of three-port DC/DC converter interface for satellite applications. IEEE Trans Power Electron. 2010; 25(3):637-49. https://doi.org/10.1109/TPEL.2009.2033926
25. Karthik DR, Reddy BM, Singh SK, Ahmed A. Application of FPGA controller in multidevice interleaved boost converter for air craft electrical systems. ICPCIT-2016. Indian Journal of Science and Technology, SRM University, Chennai. 2016; 9(44):1-7. https://doi.org/10.17485/ijst/2016/v9i44/101925
26. Mangu B, Akshatha S, Suryanarayana D, Fernandes BG. Grid-connected PV-wind-battery-based multi-input transformer-coupled bidirectional DC-DC converter for household applications. IEEE Journal. 2016; 4(3). https://doi.org/10.1109/JESTPE.2016.2544789